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Tests of the Otto gas producer

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TESTS OF THE OTTO GAS PRODUCER

BY

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STEPHEN GASKELL WOOD

THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE

IN MECHANICAL ENGINEERING

IN THE

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OF THE

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Harry Viggo Petersen and Stephen Gaskell Wood

ENTITLED Tests of the Otto Gas Producer

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Mechanical Engineering

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TEST OF OTTO GAS PRODUCER.

PRELIMINARY REMARKS.

The five tests included in this report were conducted in the Mechanical Engineering Laboratory of the University of Illinois. The data was taken and computations made in accordance with forms approved for calculations of such tests.

The object in running these tests was to determine the effect of various loads upon the operation of the producer and its efficiency with H_2 constant.

TYPES OF PRODUCERS:-

There are in general two types of producers in use, the suction producer and the pressure producer. The principle difference in these two types is the method of draft production. In the suction type the air is caused to pass thru the fuel owing to the fact that the entire system in under pressure less than atmospheric. The suction is caused by the engine, which on its inward stroke creates a partial vacuum in the producer, causing gas to rush in, thus creating a current of air thru the fuel bed. From this it may be seen that since gas is generated only when air passes over the fuel, and since this takes place only on the suction stroke of the engine, the amount of gas generated is controlled directly by the load which the engine carries. In this way automatic regulation is obtained.

In the pressure producer the conditions explained above do not hold. The air in this type is either forced through the fuel bed by a mechanical or steam blower, or it may be drawn through by a fan blower placed between the engine and

producer. In the first case the entire system is under pressure greater than atmospheric and the gas may be stored in a receiver. One objection which arises in connection with the use of this pressure system is, that unless the system is absolutely air tight, gas will be forced out into the fire-room, causing a dangerous atmosphere for the attendent to work in.

In order to secure the most efficient operation of the engine the gas must be supplied to it cold, clean and uniform in quality. This is in a measure accomplished by installing a wet scrubber between the engine and producer. This scrubber is filled with coke over which a spray of water is allowed to play. The gas in passing thru this apparatus is freed from particles of coal dust, soot and part of the tar.

In all gas producers there is a certain amount of sensible heat which must be utilized. In order to accomplish this a vaporizer for evaporating the water fed to the producer is introduced. This vaporizer contains a quantity of water which is slowly evaporated and carried into the producer in the amount corresponding to the saturation point of the air.

Since any considerable resistance to the draft in the producer and scrubber is detrimental to the engine efficiency, no elaborate scrubber system can be used in connection with the suction producer. Bituminous coal and other poorer fuels contain large amounts of tar and refuse, the removal of which requires rather complicated cleaning apparatus, for this reason the suction gas producer is limited to the use of anthracite coal and such other fuels as contain little volatile matter. Another objection to the use of poor grade fuels is that they contain a considerable

amount of fusible ash, which forms clinkers, thus interfering with the efficient operations of the producer.

THEORY OF GAS PRODUCER.

In general a simple gas producer consists of a metal retort in the bottom of which is a deep bed of incandescent fuel, thru which air is caused to pass either by suction or pressure.

The first action taking place as the air comes in contact with the fuel is the ample combustion of Carbon with Oxygen as shown in the following reaction:

$$C + O_2 = CO_2 \quad - - - - - - - (1)$$

With this reaction 14540 B.T.U..s are liberated for every pound of carbon burned. The effect of the heat thus liberated is to raise to incandescence the layer of fuel above. The CO_2 formed by reaction (1) in passing thru this incandescent layer is dissociated as follows:-

$$CO_2 + C \leftrightharpoons 2CO \quad - - - - - - (2)$$

Both temperature and time of contact of the gases passing over the carbon effect this reaction materially. At a temperature of 1650° F it is probable the combination occurs to a much greater degree than dissociation owing to the low velocities prevailing in the producer. In this discussion the reaction may be considered as taking place in one direction only.

Making a heat balance for equation (2) it is found that the reaction requires 5740 B.T.U. for every pound of carbon entering into the reaction. This quantity of heat is supplied by reaction (1). The final effect of these two reactions is shown in the formation of 4.66 lb. of CO or the partial combustion of 2 lb. of carbon, thus liberating 8800 B.T.U.

Whether the above reactions take place or whether the

carbon burns directly to CO due to insuficient air supply, the actual effect accords with the following reaction:-

$$2\,C + O_2 = 2\,CO \quad - \quad - \quad - \quad - \quad - \quad (3)$$

From the above, it can readily be seen that the heat value of the CO formed represents about 70% of that of the carbon. That part of the remaining, (30%), which does not pass off in radiation and conduction goes into raising the temperature of the producer and thus ultimately increasing it beyond reasonable limits.

In order to utilize this heat which would otherwise be lost, water is introduced and decomposed. In the decomposition Oxygen is liberated and this unites with carbon, while the Nitrogen enters directly into the composition of the gas. Two reactions may result under these conditions as follows:-

$$H_2O + C \rightleftarrows H_2 + CO \quad - \quad - \quad - \quad - \quad (4)$$

$$2H_2O + C \rightleftarrows 2H_2 + CO_2 \quad - \quad - \quad - \quad - \quad (5)$$

In this case again as in the former, reaction (4) predominates above the temperature of 1650° F. The equilibrium is here, such that the resulting composition is largely H_2 and CO.

The theoretical amounts obtained when (4) and (5) take place in connection with (3) may be obtained as follows:-

$$C + (1.33)\,O = (2.33)\,CO \quad - \quad - \quad - \quad (6)$$

The heat balance of equation (6) is:-

$$C + (1.333)\,O = 2.333\,CO$$

$$14540 \qquad = 10140 + (4400) \quad - \quad - \quad (7)$$

From this we see that (4400) B.t.u. are liberated by the reaction (7)

Making a heat balance for (4) when burning 1 lb. of carbon, we have;

$$H_2O + C \rightleftarrows H_2 + CO$$

$$1.5\ H_2O + C \rightleftarrows \tfrac{1}{6}\ H + 2\tfrac{1}{3}\ CO \quad - \quad - \quad - \quad - \quad (8)$$

$$14540 = 10333 + 10140 - (5933)$$

We see from (8) that the heat supplied by one lb. of carbon is not sufficient to complete the reaction and that (5933) B.t.u. is required in addition. Since the heat furnished for the completion of this reaction, as given by (6) is 4400, we can calculate the weights of the quantities as follows. These quantities will only be equal to $(\frac{4400}{5933})$ of those given in equation (8). or:-

$$1.112\ H_2O + .731C = .1234\ H + 1.728\ CO \qquad (9)$$

Combining equations (6) and (9) we get:-

$$1.112\ H_2O + 1.731\ C + 1.333\ O = .1234\ H + 4.061\ CO \quad -- \quad (10)$$

Reducing to unit wt of carbon:-

$$.643\ H_2O + C + .771\ O = .0713\ H + 2.33\ CO \quad - \ - \quad (11)$$

Calculating the heat equivalent of both sides of equation (11) it is found to be about 14540 B.t.u. Knowing the specific weight of O at 62° F. and 30" Hg. = .08418, of H = .0053 and of CO = .07262 and that air = .79 and (.21)O the following results may be obtained from equation (11),

Composition of Gas

CO- - -	32.1 cu. ft.	=	40.1%
H_2- - -	13.44 " "	=	16.8%
N_2- - -	34.42 " "	=	43.1%
Total	79.96		100.0

B.t.u. per. lb. of carbon = 14540

B.t.u. per cu. ft. of gas = $\frac{14540}{79.96}$ = 181 B.t.u.

Volume of gas per lb. of carbon = 79.96 cu. ft.

Weight of steam per lb. of carbon = .643 lbs.

Air required per lb. of carbon = 43.65 cu. ft.

Wt. of air required per lb. of carbon = 3.321 lbs.

In the discussion of equation (5) the same method of calculation may be followed as above with the exception that since the temperature in the producer is not great enought to cause reaction (2), reaction (1) will be used in obtaining the results.

$$3\ H_2O + C = .333\ H + 3.67\ CO_2 \quad - - - - - (12)$$

$$14540 = 20666 - (6120)$$

From this we see that (6120) B.t.u. are required to complete the reaction in addition to the heat already supplied. In order to obtain this an extra $(\frac{6120}{14540})$ lbs. of carbon must be burned. Since, when one lb. of carbon is burned 14540 B.t.u. are liberated, we can obtain from the combustion of an extra lb. of carbon $(\frac{14540}{6120})$ times the quantities formed in equation (12) or:-

$$7.125\ H_2O + 2.375\ C = .793\ H + 8.63\ CO_2 \quad - - - (13)$$

Combining equations (1) and (13);

$$7.125\ H_2O + 3.375\ C + 2670 = .793\ H + 12.29\ CO_2$$

Reducing to unit wt. of carbon:

$$2.11\ H_2O + C + .792\ O = .2347\ H + 3.642\ CO_2$$

The heat equivalent of both sides of this equation is practically 14540 B.t.u.

Knowing the specific weight of oxygen and hydrogen from the previous discussion, and that the specific weight of CO_2 at 62^{o} F and 30 in of Hg = .1161 the following results can be obtained:

Composition of Gas.

CO_2 - - - - -	31.35 cu. ft.	=	28.3%
H - - - - -	44.33 " "	=	39.9%
N - - - - -	35.32 " "	=	31.8%
	111.00		100.00

B.t.u. per lb. of carbon = 14540

B.t.u. per cu. ft. of gas = $\frac{14540}{111}$ = 131

Volume of gas per lb. of carbon = 111 cu. ft.

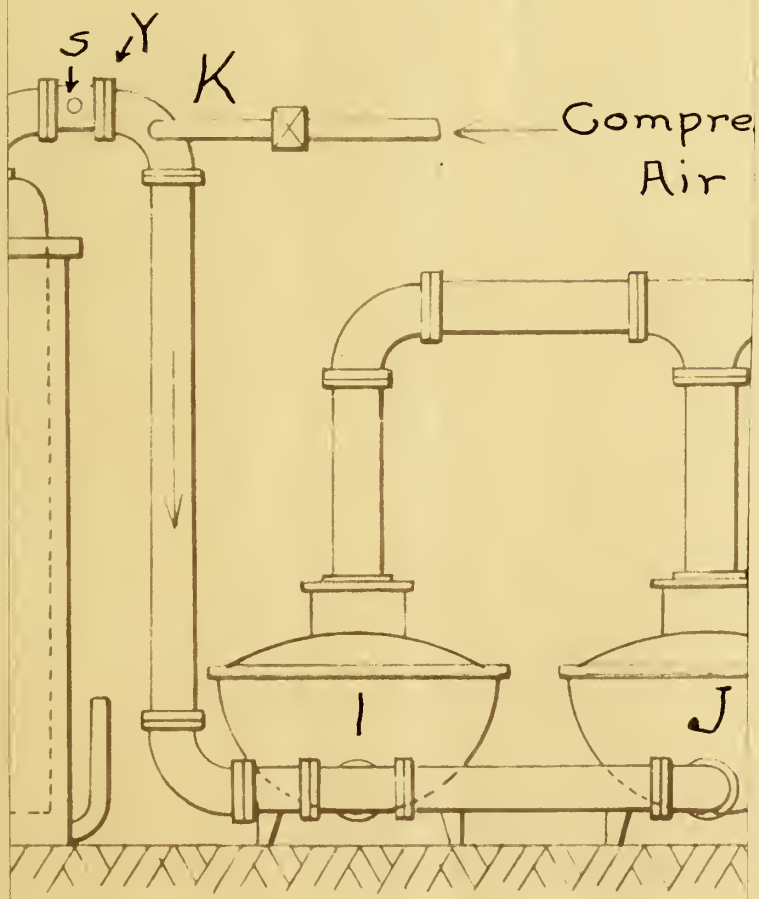
Weight of steam per lb. of carbon = 2.11 lbs.

Air required per lb of carbon = 43.8 cu. ft.

Wt. of air required per lb. of carbon = 3.63 lbs.

From the results obtained when reaction (4) takes place it may be seen that the B.t.u. per lb. of carbon is somewhat greater than in the case of equation (5). We also notice that in equation (5) more water is supplied, thus in a way accounting for the low temperature which compels the production of a large amount of CO_2 If therefore the water supply be decreased and the temperature be allowed to rise to 1650^{o} F or over the reaction (4) will take place and from comparison of results obtained by above calculations it would seem that this reaction is the better one of the two. The reason for this is that from the theoretical analysis the gas appears to be of a better and richer mixture in equation (4). It also has a considerably

larger heat content per cubic foot. It would no doubt also be better suited for gas engine operation.



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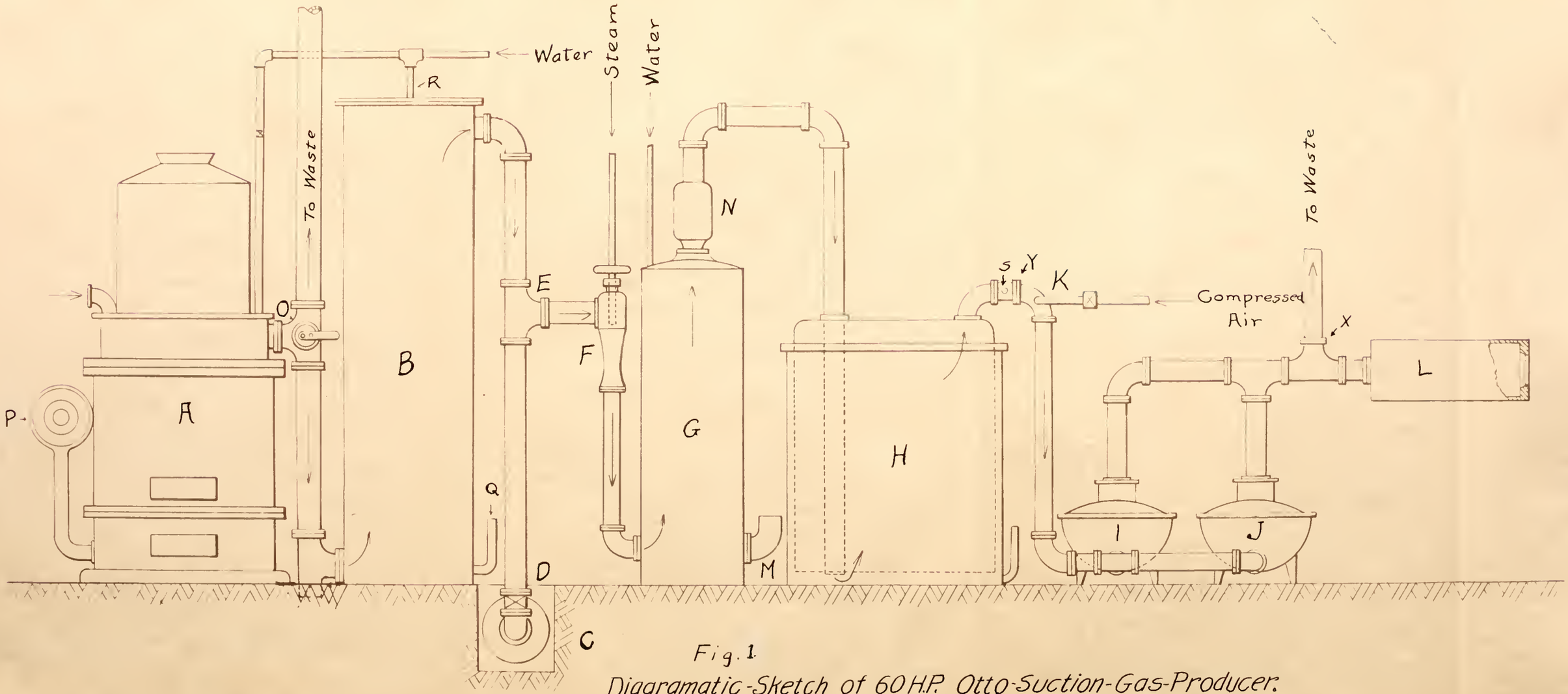


Fig. 1

Diagramatic-Sketch of 60 H.P. Otto-Suction-Gas-Producer.

DESCRIPTION OF PLANT.

In these tests a 60 H.P. Otto Gas Producer was used. In place of an engine for producing draft a Schutte-Koertnig steam ejector was installed. Some objection might be raised to this method of procedure as it is claimed that the engine produces a fluctuating suction while the ejector produces a constant one. Because of this fact it may be claimed that the conditions are not identical. Thru the work of Dr. J. K. Clement upon the equilibrium of the reaction $C + CO_2 = 2CO$ under different conditions of temperature and velocity, it has been shown that for any given temperature the CO present is materially reduced at great velocities. However, at the low velocities probably existing in the producer the amount present is practically constant. From this it can be readily seen that small variations in suction as produced by the engine would have no appreciable effect upon the composition of the gas and that the use of the ejector is justified. By the use of the ejector the following advantages are obtained: (1) A more direct control over conditions, and this may be maintained uniform thruout the test. (2) Liability of delays on starting and necessity of shutting down during the test are reduced to a minimum. (3) The necessity of working up an engine test in connection with the producer test is eliminated. (4) It isolates the producer and gives better opportunity for drawing correct conclusions.

The general arrangement of the producer and auxiliaries is shown in Fig. (1). The apparatus consists in the main of a

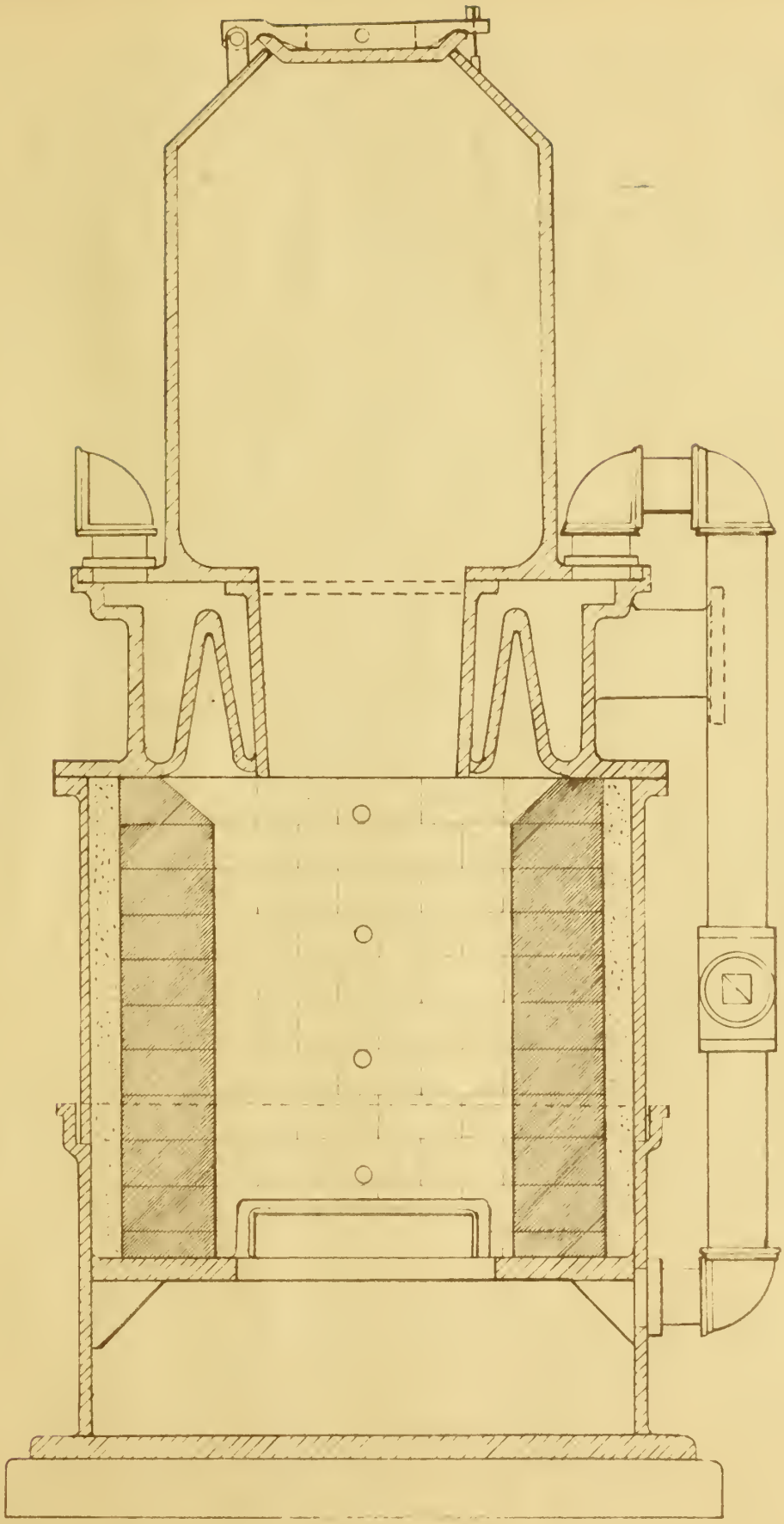


Fig. 2.

generator (A), a coke scrubber (B), a steam ejector (F), a condenser (G), a separator (N), a dryer (H), and a Westinghouse meter. In these tests only one meter was used.

The operation of the producer, simply stated, is as follows: The gas when generated passes off into the coke scrubber, where by a means of a continual spray of water over the coke, the gas is cooled and dust and tar removed. From the scrubber the gas is drawn thru the ejector and forced thru the condenser and separator. The steam from the ejector is condensed in the condenser and part of the resulting moisture in the gas is removed in the separator. From the separator the gas passes on thru the dryer and than thru the meter to waste. Such moisture as remains in the gas after leaving the separator is removed by means of straw in the dryer.

Water is introduced into the producer by means of a vaporizer with a feed pipe leading to the ashpit. The details of this construction are shown clearly in cross section Plate (2). Water is fed to the vaporizer from an overhead tank and overflows into a tank on the lower floor. Both tanks were on scales so that total water vaporized could readily be determined by their difference in weight. A small valve located between the tank overhead and the vaporizer was used for regulating the vaporizer water.

The temperature of the leaving gases was obtained by means of a Platinum-Rhodium thermo couple inserted into a thermometer cup extending into the gas chamber of the producer. The galvanometer used in connection with the thermo couple was a Siemens-Halsky mille-volt- meter calibrated in both degrees

C and milli-volts. All other temperatures were taken by means of mercury thermometers. All pressures being low, were taken by means of manometers. These manometers were placed together on one board where they could be easily and quickly read. They were connected by means of rubber hoses to the ash pit, the orifice, the meter, and the producer outlet. This made it possible to control the conditions of the test with the least trouble. A meter placed on the water feed pipe to the coke scrubber, gave correct readings of the amount of water used for scrubbing purposes.

The B.T.u. content per cubic foot of gas was determined every twenty minutes thruout the test by means of a Junker's Calorimeter. This served as a check upon the analysis by the Hempel apparatus, and also gave continual evidence of the condition of the gas being produced. The gas used in this calorimeter was taken from the same source from which the gas was drawn by the aspirator bottle. Connections were made by means of a rubber hose. The source from which the gas was drawn for these purposes was at a point midway between the dryer and the meter. The gas sampler consisted of four perforated tubes extending into the gas main. These were all brought to a common chamber to which the connections were made to the Junker's Calorimeter and aspirator bottles. Gas samples were taken by means of aspirator bottles. One bottle was filled with mercury and allowed to empty into another bottle thru a small orifice which permitted a sample to be taken over a period of approximately two hours. This gave opportunity of securing about six samples per test, and also of knowing the exact composition of the gas at any time

during the test.

The analysis of the gas was made by means of a Hempel apparatus. This apparatus consists of a long measuring burette with a leveling tube, and a number of pipettes containing reagents into which the gas is forced. The absorbing agents used were KOH solution for the CO_2, potassium pyrogallate solution for the O_2, ammoniacal cuprous chloride for CO. The CH_4 and H_2 were determined by exploding a sample in an explosion pipette. The amount of H_2 necessary to cause an explosion was obtained by the electrolytic dissociation of water. One pipette was arranged with both electrodes in the same chamber, and produced oxy-hydrogen ready for an explosion which was added to cause the combustion. As this was already in the proper uniting proportions, it would dissappear upon explosion and would not effect the other constituents in any way but to raise the temperature up to the combustion point. It was therefore not necessary to measure the amount added. The oxygen added to unite with CH_4 and H_2 was obtained in the same manner as the oxy-hydrogen, except the collecting chamber contained the positive electrode alone. By use of this arrangement it was found that the determinations of CH_4 and H_2 could be made to check within less than one percent.

METHOD OF CONDUCTING TESTS.

After cleaning the producer of all clinkers and ashes which might have remained from previous tests and examining the scrubber to see that it was in good working order, the fire in the producer was started. For this purpose kindling and inflamable material was placed in the fuel bed and the magazine was filled with several large buckets of coal. Immediately after lighting the fire the ejector was set in operation. A rather heavy draft was maintained until the temperature of the fuel bed had been raised to the proper point. A sample calculation of the heat value of the gas was then made by the Junker's Calorimeter. When this was found satisfactory, the fire was cleaned from below and the magazine was filled to the top with coal. A sample of this coal was taken at intervals during the time of filling and also at those times during the rest of the test when the producer was fired.

After these preliminary operations, the ejector was regulated to produce the proper flow of gas in cubic feet thru the meter. This draft was then carefully watched and kept as constant as possible consistent with a uniform load. The test was thus started under constant conditions and continued for twelve hours.

Upon the signal to start readings were taken of the following pressures; at meter, in the ash pit, at the producer outlet and at the orifice; temperatures; at meter, of gas leaving producer and the scrubber, of the fire room, of water entering and leaving the scrubber and vaporizer; initial readings were also taken of the gas and water meters as well as of the

tanks on scales. Readings were taken every fifteen minutes. The Junker's Calorimeter gave by calculations, the heating value of the gas about every twenty minutes, it requiring about fifteen minutes to fill the eight liter jar used in connection with this apparatus, with water. The gas samples, taken by means of aspirator bottles were timed so that a sample of gas could be obtained about every two hours. These samples of gas were sent to the chemist for analysis.

If at any time during the test the heating value of the gas was found to decrease and the temperature in the fuel bed became low, the fire was cleaned, that is,the producer was poked from above and sliced from below. This always had to be done with great care owing to the liability of the gas becoming incombustible. At such times as the fuel in the magazine fell below a normal amount more fuel was added thru the opening in the top of the producer. This fuel was always carefully weighed and samples kept out. All ash removed during fire cleaning was placed in a can and saved to be weighed and sampled at the close of the test.

In closing the test conditions were brought as near those of starting as possible. The fire was cleaned and ash removed from the ash pit and placed in the ash can. The magazine was then filled and careful account of coal thus used was taken. The ash and refuse was weighed. Both ash and coal were crushed and samples of each bottled and sent to the chemist.

RESULTS OF GAS PRODUCER TRIALS.

KIND OF FUEL . . . . . Anthracite for all tests.

COMMERCIAL NAME OF FUEL . . . . . Scranton Pea.

	TEST NUMBER	41	42	43	44	45
	DATE OF TRIAL, ...	2-1-10	2-18-10	2-23-10	2-25-10	3-2-10
	DURATION OF TRIAL, HRS.	12	12	12	12	12
1	Dimensions of grate, ft.----------	1.25x1.33	-do-	-do-	-do-	-do-
2	Grate area, sq. ft.----------	1.666	"	"	"	"
3.	Mean diameter of fuel bed, ft.----------	1.545	"	"	"	"
4	Depth of fuel bed, ft.----------	2.210	"	"	"	"
5	Area of fuel bed, sq. ft.----------	1.877	"	"	"	"
6	Height of discharge pipe above grate, ft----------	2.875	"	"	"	"
7	Approximate width of air spaces in grate, in. ----	.500	"	"	"	"
8	Area of air space, sq. ft.----------	.722	"	"	"	"
9	Proportion of air space to whole grate area %--	43.300	"	"	"	"
10	Area of discharge pipe, sq. ft.----------	1.650	"	"	"	"
11	Water heating surface in vaporizer, sq. ft.------	-------	"	"	"	"
12	Outside dia. of shell, ft.----------	2.833	"	"	"	"
13	Length of shell from base to top of magazine, ft	7.125	"	"	"	"
14	Ratio of water heating surface to grate area--to 1	-------	"	"	"	"
15	Ratio of minimum draft area to grate area 1 to --	48.800	"	"	"	"
	Average Pressure					
16	Average barometer reading ins, Hg.----------	29.469	29.27	29.85	29.3	29.45
17	Average corrected barometer reading, ins, Hg.----	29.395	29.25	29.75	29.2	29.37
18	Draft in ash pit, inches water----------	.2368	.35	.957	.774	.2858
19	Suction at producer outlet, ins. water----------	.6510	1.35	.3345	2.82	1.156
20	Abs. pressure at producer outlet, ins. Hg.-------	29.347	29.151	29.7253	28.993	29.285

21	Suction at orifice, ins. water	.0546	.142	.0245	.298	.1091
22	Abs. pressure at orifice, ins. Hg.	29.390	29.241	29.748	28.981	29.3619
23	Pressure at meters, ins. water	1.102	2.41	1.271	9.19	4.470
24	Abs. pressure at meters, ins. Hg.	29.476	29.422	29.843	29.876	29.698
25	Vapor pressure at meters, ins. Hg.	.600	.4896	.564	.5385	.567
26	Dry gas pressure at meters, ins. Hg.	28.876	28.9324	29.279	29.337	29.1315
27	Suction at meter for dryer, ins. water	----	----	----	----	----
28	Abs. pressure at meter for dryer, ins. Hg	----	----	----	----	----
	Average Temperatures.					
29	At barometer, deg. F	69.5	59.75	66.72	61.7	61.94
30	Of fire room, deg. F	71.15	61.3	65.34	62.9	61.94
31	Of fire room, deg. abs. F	531.15	521.3	525.34	522.9	521.94
32.	Of steam, deg. F	212.0	212	212	212	212
33	Of feed water entering vaporizer, deg. F	62.75	57.5	62.35	61.6	65.8
34	Overflow from vaporizer, deg. F	191.0	176.7	179.0	176.8	179.75
35	Rise in vaporizer, deg. F	128.25	119.2	106.65	115.2	113.95
36	Of water entering scrubber, deg. F	55.4	54.3	54.25	55.1	55.35
37	Of water leaving scrubber, deg. F	92.8	100.8	74.04	119.7	92.35
38	Rise in scrubber, deg. F	37.4	46.5	19.79	64.6	37
39	Of gases leaving producer deg. F	482.0	673	356	682	542
40	Of gases leaving producer, deg. abs. F	942.0	1133	816	1142	1002
41	Of gases leaving first scrubber, deg. F	73.03	60.8	75.48	95	75.25
42	Of gases leaving first scrubber, deg. abs. F	533.03	520.8	535.48	555	535.25
43	Drop in temperature of gases in scrubber, deg. F	408.97	602.2	280.52	567	466.75
44	Of gases entering meters, deg. F	61.2	58.2	60.36	61.75	62.25
45	Of gases entering meters, deg. abs. F	521.2	518.2	520.36	521.75	522.25
46	Of gas at meter at dryer, deg. F	-----	----	----	----	----
47	Of gas at meter at dryer, deg. abs. F	-----	----	----	----	----
	F U E L					
48	Size and condition	Pea clean	do	do	do	do
49	Weight of coal as fired, lb	268	493.5	236	749	419
50	Percentage of moisture in coal	.33	1.03	1.23	1.90	1.03
51	Total weight of dry coal fired, lb.	267.2	488.5	233.1	734.5	414.7
52	Total ash and refuse, lb	76.5	188.1	112.5	341	147.8
53	Quality of ash and refuse	----	----	----	----	----

54	Total weight of combustible, lb.	170.4	276.1	118.1	397.84	233.3
55	Percentage of ash and refuse in dry coal %	28.6	38.5	48.25	46.46	35.67
	Proximate analysis of coal					
56	Fixed carbon	76.92	78.21	77.8	79.59	77.9
57	Volatile matter	6.77	5.72	5.62	5.33	5.62
58	Moisture	.33	1.03	1.23	1.90	1.03
59	Ash	15.98	15.04	15.35	13.18	15.45
60	Sulphur, separately determined	1.55	1.12	1.12	1.09	1.12
	Ultimate analysis of dry coal					
61	Carbon (C) %	77.597	79.5	79.2	81.53	79.02
62	Hydrogen (H_2)	2.509	2.14	2.17	2.22	2.19
63	Oxygen (O_2)	1.816	1.64	1.568	1.35	1.64
64	Nitrogen (N_2)	.483	.41	.392	.34	.41
65	Sulphur (S)	1.557	1.13	1.13	1.12	1.13
66	Ash	16.038	15.18	15.54	13.44	15.61
67	Moisture in sample of coal as received %	.33	1.03	1.23	1.90	1.03
	Analysis of dry ash and refuse					
68	Carbon, %	61.83	67.67	65.66	73.32	73.21
69	Earthy matter, %	38.06	31.95	34.25	26.35	21.81
	1 SiO_2					
	2 Al_2O_3					
	Fe_2O_3					
	3 MgO					
	4 CaO					
	Fuel per hour					
70	Dry coal fired per hour, lb	22.27	40.71	19.42	61.208	34.56
71	Combustible consumed per hour, lb	14.195	23.01	9.75	31.653	19.44
72	Dry coal per sq. ft. of grate area per hour, lb	13.36	24.45	11.65	36.75	20.725
73	Combustible per sq. ft. of grate area per hour, lb	8.522	13.81	5.85	19.01	11.66
74	Dry coal per sq. ft. of fuel bed per hour, lb	11.86	14.16	10.35	32.616	18.405
75	Combustible per sq. ft. of fuel bed per hour, lb	7.565	12.26	5.195	16.866	10.36

76	Rate of descent of dry coal thru fuel bed, lb per ft. per sq. ft. per hour	5.365	6.41	4.685	14.759	8.335
77	Rate of descent of combustible thru fuel bed, lb. per ft. per sq. ft. per hour	3.422	5.55	2.351	7.6325	4.690
	Calorific value of fuel					
78	Calorific value by oxygen calorimeter per lb. dry coal, B. t. u.	12580	12560	12475	12780	12475
79	Calorific value by oxygen calorimeter per lb. combustible, B. t. u.	15695	15520	15540	15140	15425
80	Calorific value by analysis, per lb. dry coal, B. t. u.	12758.3	12820	12790	13171.5	12755.2
81	Calorific value by analysis, per lb. combustible, B.t.u.	15975	15650	16080	15901	15920
	W a t e r					
82	Total weight fed to vaporizer, lb	622.5	849.0	267	1055	644
83	Total weight of overflow, lb	307.5	307.5	139.5	332	222.5
84	Water actually evaporated in vaporizer, lb	315.0	541.5	127.5	723	421.5
85	Total weight of water fed to producer, lb	329.034	562.99	133.71	759.55	440.05
	a From vaporizer	315	541.5	127.5	723	421.5
	b In air	13.15	16.35	5.315	22.32	14.24
	c In coal	.884	5.14	2.9	14.23	4.315
86	Total weight of water decomposed from analysis, lb	79.01	153.18	46.93	196.9	110.133
87	Total weight of water decomposed as used in calculations, lb	79.01	153.18	46.93	196.9	110.133
88	Total weight of moisture in gas leaving producer lb	250.024	409.81	85.785	562.65	329.922
89	Ratio of water decomposed to water supplied	.24	.2722	.3525	.2591	.2499
90	Weight of water decomposed per lb. of gas generated, lb	.0584	.0625	.0551	.0652	.05881
91	Weight of water decomposed per lb. of dry coal fired lb	.296	.3137	.2014	.2679	.2657
92	Weight of water decomposed per lb. of combustible consumed, lb	.4635	.5544	.3975	.5184	.472
93	Weight of water decomposed per lb. of air supplied	.0683	.0784	.0635	.0782	.07185

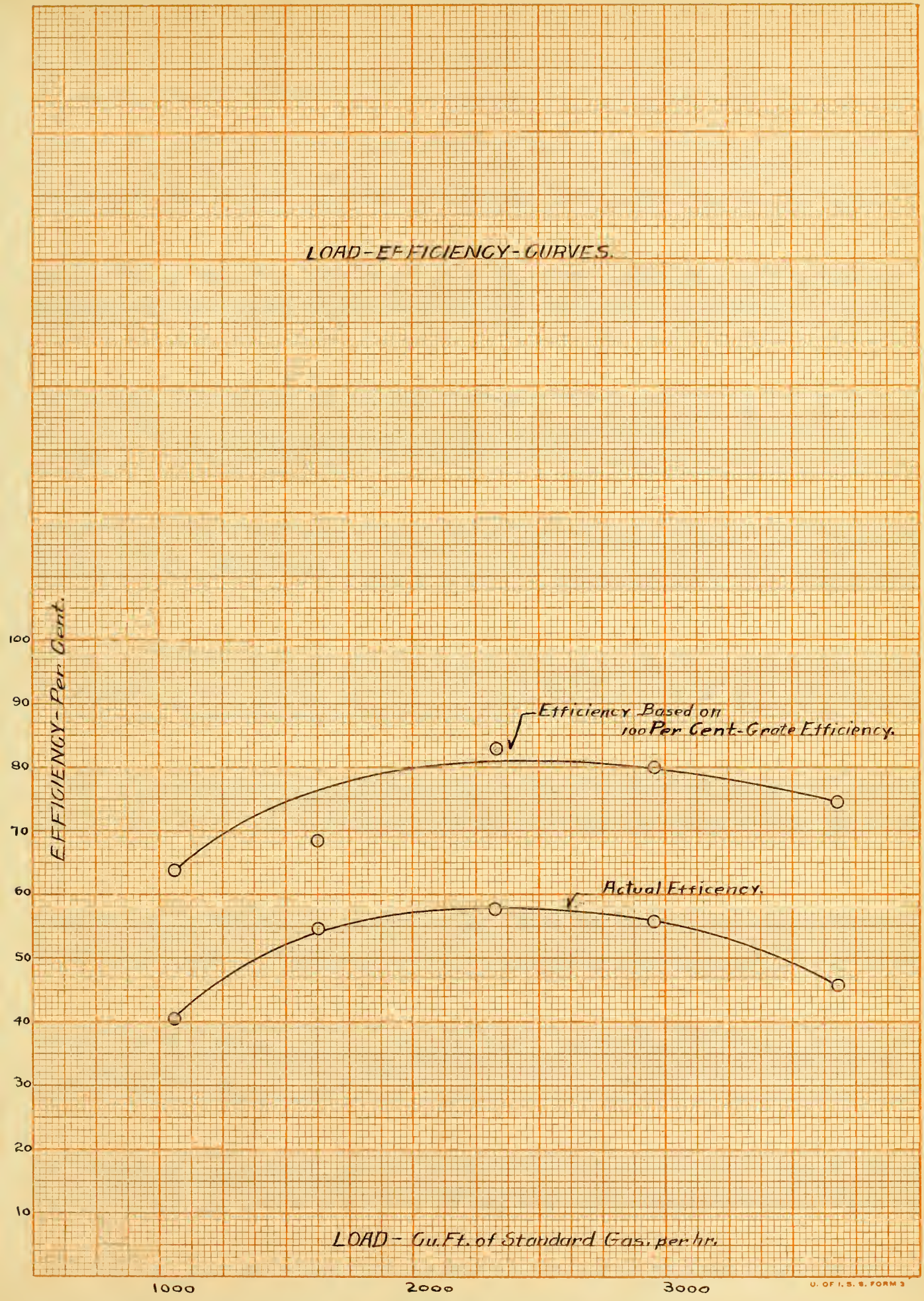
94	Weight of water supplied per lb. of dry coal fired, lb	1.191	1.151	.5731	1.033	1.0615
95	Weight of water supplied per lb. of combustible consumed, lb	1.931	2.036	1.132	1.999	1.885
96	Weight of water supplied per lb. of air used lb	.285	.288	.1811	.032	.287
97	Total weight of scrubber water, lb	11490	18300	9680	17070	14475
98	Total weight of water absorbed by dryer, grams	-----	-----	-----	-----	-----
	Water per hour					
99	Water evaporated per hour in vaporizer, lb	26.24	45.1	10.62	60.25	35.13
100	Water evaporated per hour per sq. ft. of water heating surface in vaporizer, lb	-----	-----	-----	-----	-----
101	Weight of water decomposed per hour, lb	6.585	12.77	3.912	16.4	9.18
102	Total weight of water fed to producer per hr. lb	27.43	46.91	11.14	63.29	36.68
103	Weight of scrubber water used per hour, lb	957	1525	806.6	1422.5	1020.6
	Quantity of air					
104	Relative humidity of air %	70	73	55	74	80
105	% of moisture contained in air, % by weight of dry air	1.138	.8362	.7992	.888	.9269
106	Total weight of dry air by analysis, lb	1157	1955	738.5	2515	1534
107	Total weight of dry air by orifice, lb	-----	-----	-----	-----	-----
108	Total weight of dry air as used in calculations, lb	1157	1955	738.5	2515	1534
109	Weight of dry air per hour from total used in calculations	96.4	162.85	61.38	209.58	127.8
110	Weight of dry air used per lb. of dry coal fired lb	4.33	4.00	3.158	3.421	3.701
111	Weight of dry air used per lb. of combustible consumed, lb	6.795	7.08	6.235	6.62	6.575
112	Weight of dry air used per lb. of dry gas generated, lb	.855	.797	.8645	.8335	.820
	G a s					
113	Volume of gas passing thru meter at dry cu. ft.	----	----	----	----	----
114	Volume of Standard Gas passing thru meter at dryer cu. ft.	----	----	----	----	----

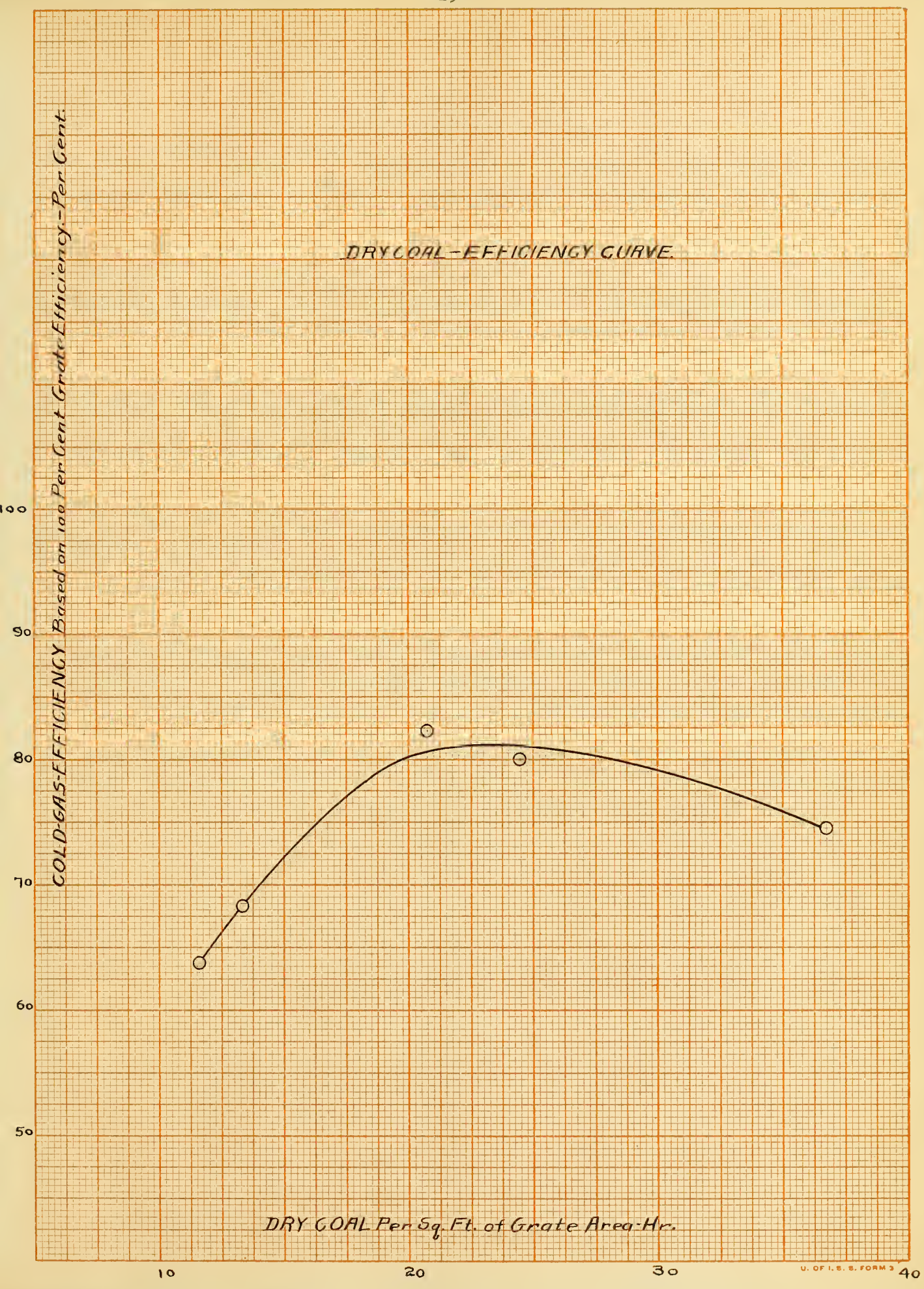
115	Total weight of gas passing thru dryer meter, lb	----	----	----	----	----
116	Percentage of moisture in gas leaving producer, from dryer, %, dry gas	----	----	----	----	----
117	Percentage of moisture in gas leaving producer, from water fed to producer, % dry gas	18.525	18.65	10.061	18.65	17.6
118	Percentage soot and tar in gas leaving producer %	----	----	----	----	----
119	Calorific value per cu. ft. of Standard Gas from analysis, B. t. u. (High Value)	94.	96.5	92	96.096	106.6
120	Calorific value per cu. ft. of Standard Gas from calorimeter, B. t. u. (High Value)	103.9	104	96.79	102.65	113.7
121	Specific weight of Standard Gas, lb. per cu. ft.	.0691	.0691	.06865	.06835	.06735
122	Specific heat of dry gas leaving producer	.2936	.3076	.28794	.31111	.30513
123	Carbon ratio C/H	10.092	10.94	9.29	9.38	9.14
124	Total volume of gas from meters, cu. ft.	19980	36043	13020	45120	28800
125	Total volume of Standard Gas, from meters, cu.ft	19550	35500	12740	44170	27970
126	Total volume of Standard Gas, from analysis, cu. ft.	19400	29850	15100	44610	26940
127	Total volume as used in calculations, cu. ft.	19550	35500	12740	44170	27970
128	Volume of Standard Gas per hour from total used in calculations	1629	2958	1061.7	3680.8	2330
129	Volume of Standard Gas per lb. of dry coal from total used in calculations, cu. ft.	73.15	72.625	54.62	60.1	67.5
130	Volume of Standard Gas, per lb. of combustible from total used in calculations, cu. ft.	114.7	128.49	107.8	116.3	119.7
131	Total weight of Standard Gas from total used in calculations, lb	1352	2452	852.0	3018	1873
132	Weight of Standard Gas per hour, lb	112.6	204.3	70.92	251.5	156.1
133	Weight of Standard Gas per lb. of dry coal, lb	5.055	5.02	3.65	4.108	4.52
134	Weight of Standard Gas per lb. of combustible, lb	7.94	8.8	7.21	7.95	8.03
	Gas analysis by volume					
135	Carbon dioxide (CO_2)	9.66	10.55	10.02	11.24	9.917
136	Carbon monoxide (CO)	13.78	16.40	12.52	12.98	15.216
137	Oxygen (O_2)	1.38	1.525	1.18	.95	1.15
138	Hydrogen (H_2)	12.84	13.45	13.78	14.94	15.433
139	Marsh gas (CH_4)	.78	.775	.66	.56	.75
140	Olefiant gas (C_2H_4)	----	----	----	----	----
141	Sulphur dioxide (SO_2)	----	----	----	----	----

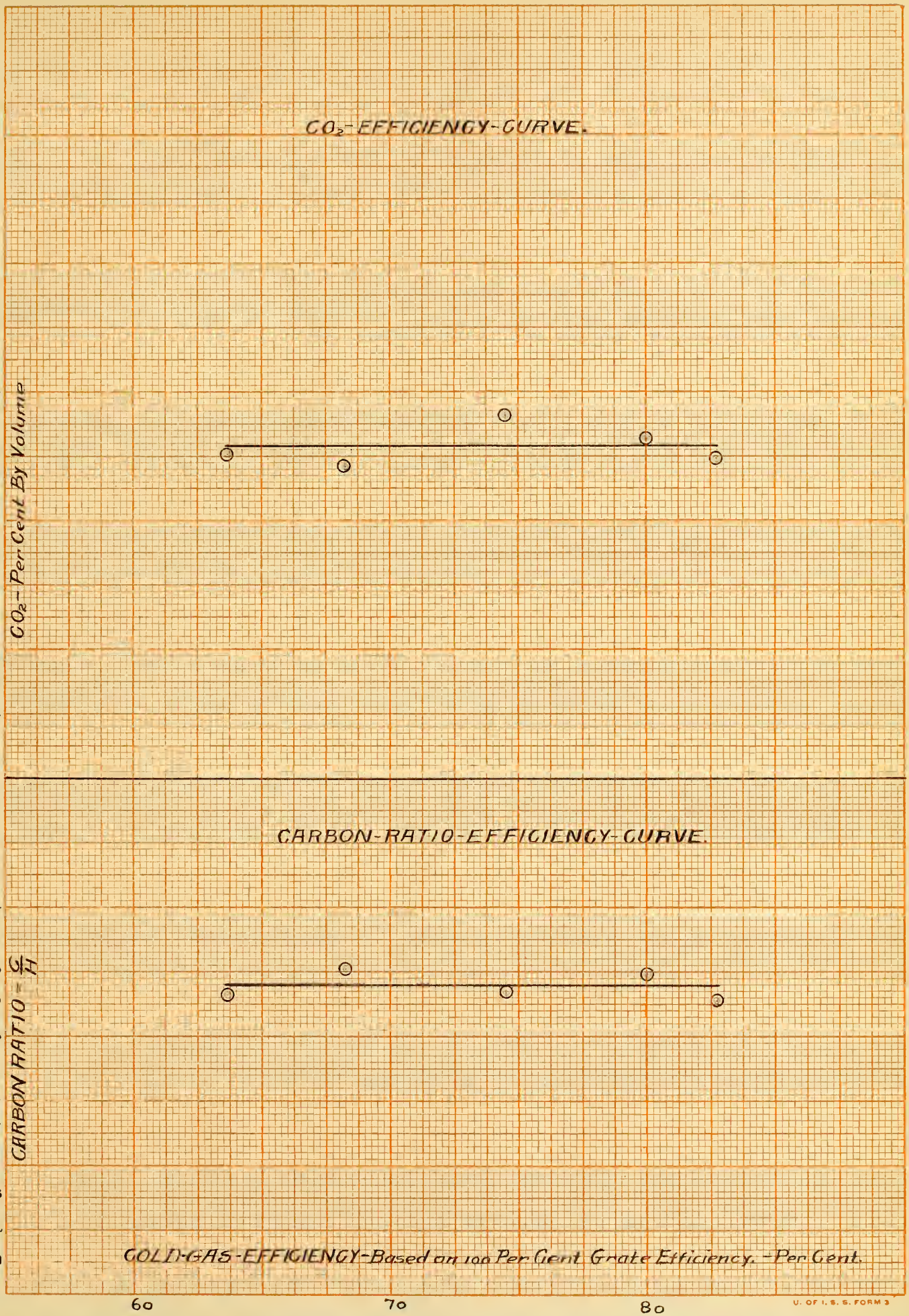
142	Hydrogen sulphide (H_2S)	----	----	----	----	----
143	Nitrogen (N_2)	61.56	57.3	61.84	59.33	57.534
	Gas analysis be weight					
144	Carbon dioxide (CO_2)	16.23	17.75	16.91	19.17	17.07
145	Carbon monoxide (CO)	14.68	14.46	13.43	13.98	16.62
146	Oxygen (O_2)	1.68	1.85	1.46	1.15	1.43
147	Hydrogen (H_2)	.98	1.04	1.05	1.14	1.21
148	Marsh gas (CH_4)	.48	.48	.41	.34	.47
149	Olefiant gas (C_2H_4)	----	----	----	----	----
150	Sulphur dioxide (SO_2)	----	----	----	----	----
151	Hydrogen sulphide (H_2S)	----	----	----	----	----
152	Nitrogen (N_2) by difference	65.95	61.42	66.74	64.22	63.20
	Efficiency					
153	Grate efficiency °/o	80.15	69.8	63.05	61.44	69.65
154	Hot gas efficiency, based on high heating value, per cent	69.10	75.0	46.5	59.76	71.3
155	Cold gas efficiency, based on high heating value per cent	54.70	57.78	40.22	45.70	57.65
a 155a						
	Cost of gasification					
156	Cost of fuel per ton delivered in producer room					
157	Cost per 1000 cu. ft. of Standard Gas, cts					
158	Cu. ft. scrubber water per 1000 cu. ft. Standard Gas	9.41	8.25	12.15	6.2	8.28
	P o k i n g					
159	Method of poking (From top to bottom)					
160	Frequency of poking					
	F i r i n g					
161	Method of firing (By hand without bell)					
162	Average intervals between firing					
163	Average amount of fuel charged each time					

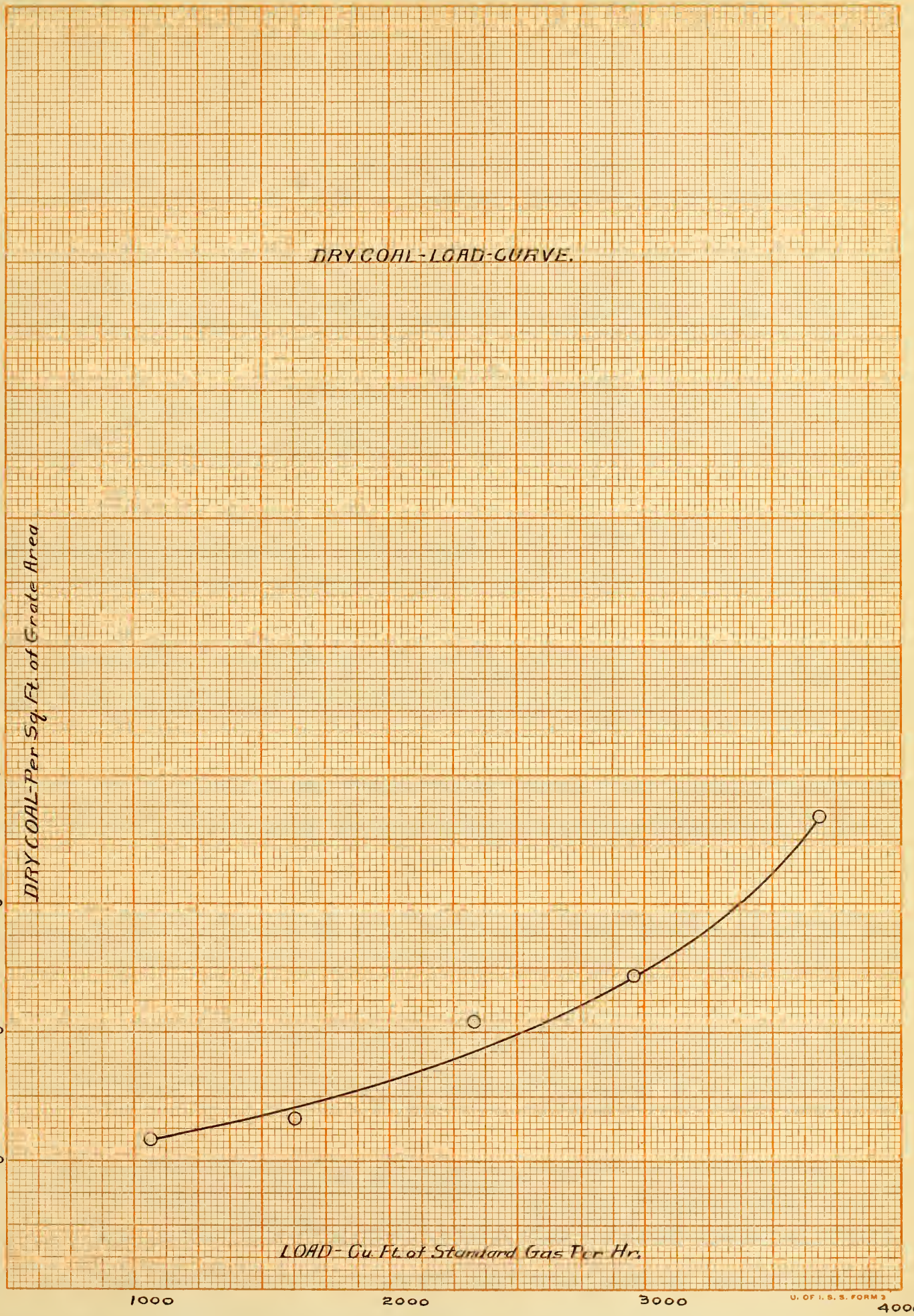
Heat Balance

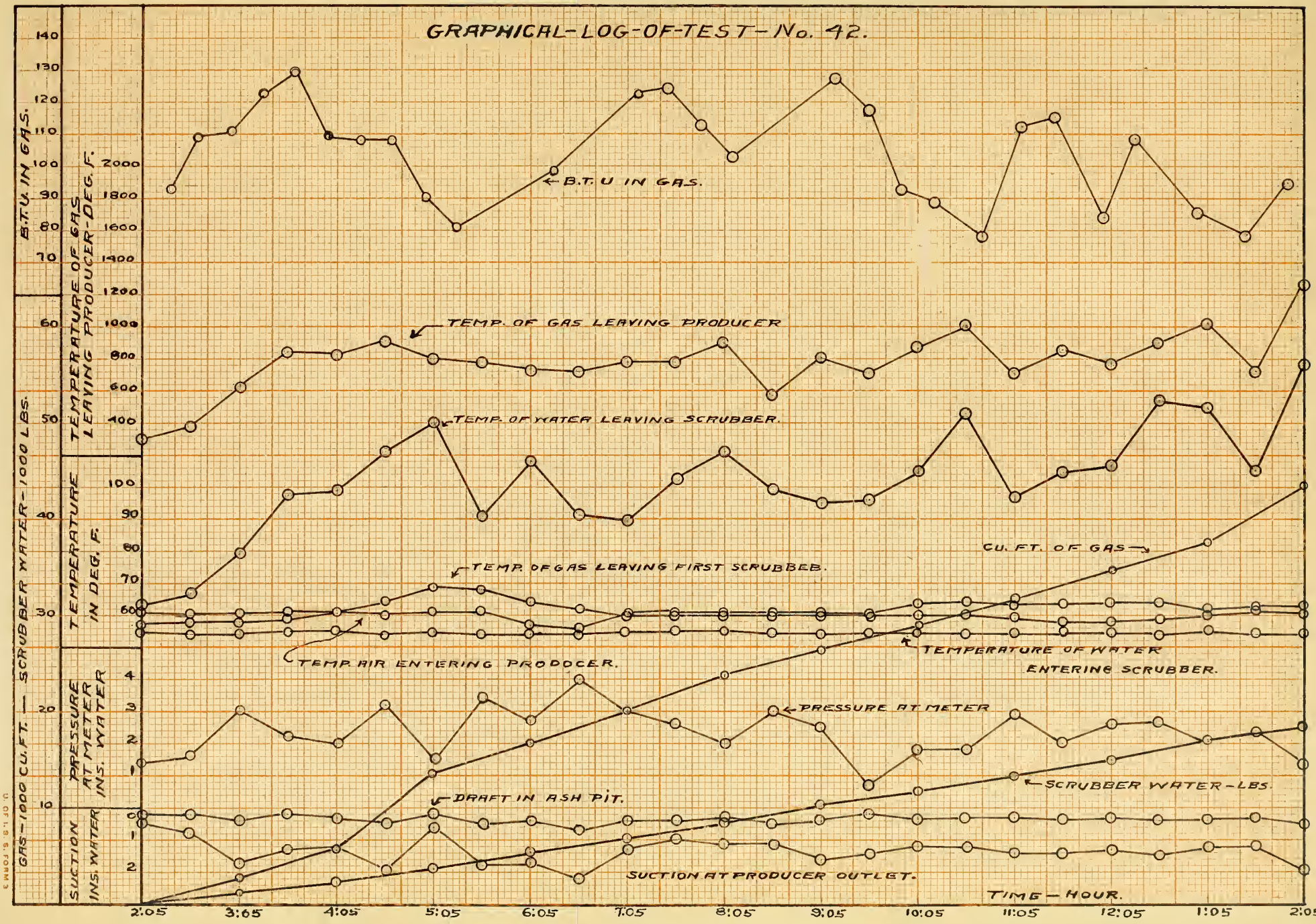
	Debit					
1	Total heat supplied per lb. dry coal B.t.u.	12580	12560	12475	12780	12475
2	Total heat supplied by air per lb dry coal	9.51	---	10.54	---	---
3	Total heat supplied by moisture in air per lb. dry coal	---	---	---	---	---
4	Total heat supplied by moisture in coal	---	---	---	---	---
5	Total heat supplied as sensible heat in coal	---	---	---	---	---
6	Total heat supplied in vaporizer water	1.75	7.83	---	---	5.9
	TOTAL	12591.26	12552.17	12485.54	12780	12480.9
	Credit					
1	Heat contained as sensible heat in dry gas B.t.u.	623.5	944.0	309.1	792.6	662.1
2	Heat contained in moisture	1198.0	1304.0	441.5	1071.0	797.0
3	Heat contained in dry gas, (Heat of combustion)	6888.0	7020.0	5030.0	5772.0	7200.0
4	Heat in unburned carbon	2572.0	3790.0	4615.0	4943.0	3795.0
5	Heat contained as sensible heat in ash and refuse	---	---	---	---	---
6	Heat lost in overflow from vaporizer	148.4	72.3	-70.0	51.9	63.21
7	Radiation and conduction, by difference	1161.36	365.87	2019.94	149.5	36.41
		12591.26	12552.17	12485.54	12780.0	12480.9
155a[a]	Cold gas efficiency based on 100% Grate efficiency	68.25	80	63.7	74.5	82.7

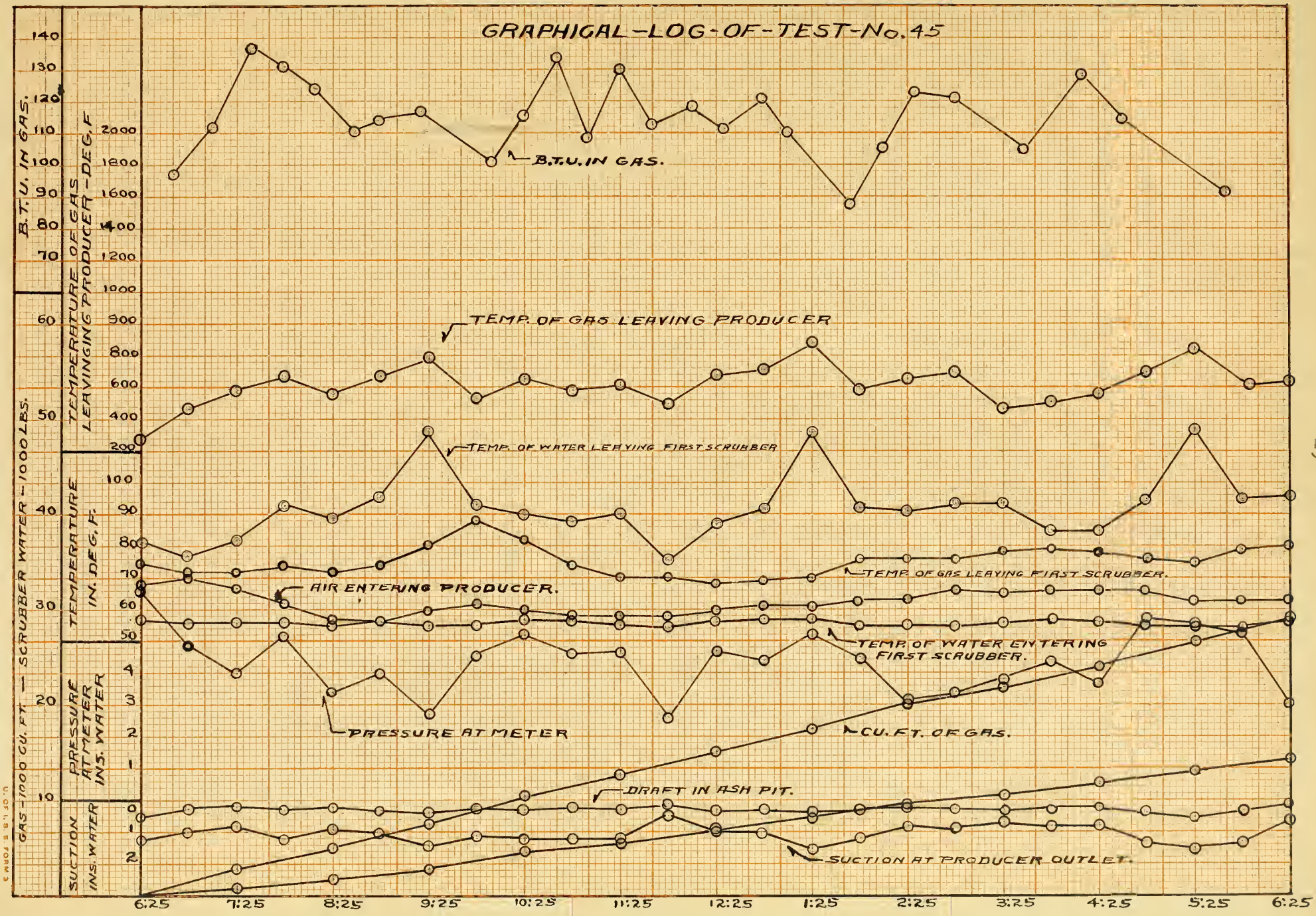

LOAD-EFFICIENCY-CURVES.
EFFICIENCY-Per Cent.
100
90
80
70
60
50
40
30
20
10
Efficiency Based on
100 Per Cent-Grate Efficiency.
Actual Efficency.
LOAD-Cu.Ft. of Standard Gas. per hr.
1000
2000
3000
U. OF I. S. S. FORM 3


DRY COAL - EFFICIENCY CURVE.
COLD-GAS-EFFICIENCY Based on 100 Per Cent Grate Efficiency - Per Cent.
100
90
80
70
60
50
DRY COAL Per Sq. Ft. of Grate Area-Hr.
10
20
30
40
U. OF I. S. B. FORM 3


CO_2-EFFICIENCY-CURVE.
CO_2-Per Cent By Volume
12
11
10
9
8
7
6
5
4
3
2
1
CARBON-RATIO-EFFICIENCY-CURVE.
CARBON RATIO = $\frac{C}{H}$
12
11
10
9
8
7
6
5
4
3
2
1
SOLID-GAS-EFFICIENCY-Based on 100 Per Cent Grate Efficiency. -Per Cent.
60
70
80
U. OF I. S. S. FORM 3


DRY COAL - LOAD - CURVE.
DRY COAL - Per Sq. Ft. of Grate Area
40
30
20
10
LOAD - Cu Ft. of Standard Gas Per Hr.
1000
2000
3000
4000
U. OF I. S. S. FORM 3


GRAPHICAL-LOG-OF-TEST-No. 42.
B.T.U. IN GAS.
TEMPERATURE OF GAS LEAVING PRODUCER-DEG. F.
TEMPERATURE IN DEG. F.
PRESSURE AT METER INS. WATER
SUCTION INS. WATER
GAS-1000 CU. FT. — SCRUBBER WATER-1000 LBS.
B.T.U IN GAS.
TEMP. OF GAS LEAVING PRODUCER
TEMP. OF WATER LEAVING SCRUBBER.
TEMP. OF GAS LEAVING FIRST SCRUBBER.
TEMP. AIR ENTERING PRODUCER.
CU. FT. OF GAS
TEMPERATURE OF WATER ENTERING SCRUBBER.
PRESSURE AT METER
SCRUBBER WATER-LBS.
DRAFT IN ASH PIT.
SUCTION AT PRODUCER OUTLET.
TIME-HOUR.
2:05
3:05
4:05
5:05
6:05
7:05
8:05
9:05
10:05
11:05
12:05
1:05
2:05


GRAPHICAL-LOG-OF-TEST-No. 45
B.T.U. IN GAS.
TEMPERATURE OF GAS LEAVING PRODUCER - DEG. F
TEMPERATURE IN DEG. F.
PRESSURE AT METER INS. WATER
SUCTION INS. WATER
GAS-1000 CU. FT. — SCRUBBER WATER-1000 LBS.
B.T.U. IN GAS.
TEMP. OF GAS LEAVING PRODUCER
TEMP. OF WATER LEAVING FIRST SCRUBBER
TEMP. OF GAS LEAVING FIRST SCRUBBER.
AIR ENTERING PRODUCER.
TEMP. OF WATER ENTERING FIRST SCRUBBER.
PRESSURE AT METER
CU. FT. OF GAS.
DRAFT IN ASH PIT.
SUCTION AT PRODUCER OUTLET.
6:25
7:25
8:25
9:25
10:25
11:25
12:25
1:25
2:25
3:25
4:25
5:25
6:25

CONCLUSIONS.

From the results obtained by the calculations of the five tests described in this report, the following conclusions may be drawn:-

(1) A glance at the Load-Efficiency curves will show that on a basis of 100 present grate efficiency, the efficiency of the producer reaches a maximum at a load of about 2500 cubic feet of gas per hour, after which it falls off slightly. This falling off is perhaps largely due to the method of poking and slicing, as on the heavy loads more poking and slicing must be done than in the case of a lighter load. If, therefore, these operations could be performed more efficiently the efficiency of the producer would no doubt continue at a higher value to a greater load than is shown by the curve.

(2) The Dry Coal-Efficiency curve shows practically the same conditions as does the Load-Efficiency curve. Here it can be seen that for a certain amount of coal fired per sq. ft. of grate area, the efficiency is at a maximum, and as this amount increases the efficiency falls off. This corresponds to the increasing of the load, in which case the efficiency also fell off. The amount of dry coal per sq. ft. of grate area, at which the maximum efficiency occurred, as shown from the curve is about twenty-two (22) lbs.

(3) The variation of CO_2 with the efficiency is also clearly shown in the CO_2 Efficiency curve. From this curve it appears that the CO_2 generated stays practically constant and is not affected by the efficiency of the producer. In the case of the Carbon Ratio, we find the same conditions hold true, as those

for CO_2. From the Carbon Ratio-Efficiency curve we see that the carbon ratio remains practically constant and it would seem that it was entirely independent of the variation of efficiency.

(4) The Dry Coal-Load curve gives in a measure some idea of the accuracy of the work as performed in these tests. The curve should from its nature be a hyperbola and it can be seen that it approaches very closely this form. The two graphical log sheets which also accompany this report, show clearly the conditions existing during the time of running the tests.

In order to obtain the best results in these tests it was found necessary to first poke the producer from above and then slice it from below. In this manner the gas could be kept burning at the Junker's Calorimeter and thus the loss of calculations of the heating value of the gas could be avoided. The reason for this is that when the fire is cleaned from below first, the coal remains arched in the magazine, thus creating a hollow space, which fills with air, when the poking from above is being done. Poking from above first removes this condition and loosens the coal in the magazine, so when the slicing is done from below the coal finds little difficulty in falling into place and thus continue the gasification. It is no doubt true that a bell hopper at the top of the magazine would materially increase the efficiency of the producer, for there would be less opportunity for an oversupply of air to enter and cause the consequent cooling effect to take place.

It seems evident that in order to insure commercial success for this type of producer a more efficient means of poking and firing is needed than the method now used.

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